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ADDRESS OF THE PRESIDENT:

THE INFLUENCE OF ELECTRICITY ON PROTOPLASM.

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In glancing over the themes presented by the past presidents of this society at the annual meetings over which they have been called to preside, it is noticeable that they include a wide variety of subjects. This could not well be otherwise, when the vastness of the field in which the microscope is an indispensable factor is considered. Blot vision (which the microscope so wonderfully enlarges) from the functions, and what is left to be appreciated? This instrument, which gives its name to our association, is the single factor which teaches us beyond the power of words to delineate how circumscribed is the cycle of nature which the unaided sense of sight may compass. Hence it is not strange that in the presidential addresses of past years themes of the specialist in microscopic investigation, those historical, with others of general interest on the subject, should be presented. From this I assume that no rule is prescribed to guide us in the selection of a topic for your consideration. It appears to be acknowledged in the introduction to several of these discourses that the subject should be made somewhat popular, in deference, no doubt, to the ladies and gentlemen, not specialists, who are interested enough in our labor to grace us with their presence.

In the selection of an address entitled *The Influence of Electricity*

on Protoplasm, it may be urged that the presentation of a popular paper with such indefinite topics for the subject is almost a hopeless endeavor. Had I other than an American audience, qualified by our advanced educational methods to appreciate intelligently discourses on almost any subject, I might have chosen one less technical in character.

What in part has called the attention of the world to the influence existing between these remarkable agents is that in the medical world, at home and abroad, an awakening interest in the therapy of electricity has lately been aroused; unusual activity prevails; electricity is utilized more frequently than ever before in this field, and a more systematic method of application is in vogue. Another factor also is the controversy, even now in progress, relating to the application of electricity in the execution of criminals. How death is produced by powerful electric influences, from a technically scientific standpoint, is as yet unsettled. It is reasonably anticipated that the investigations by many workers, lately undertaken, may result in clearing up the existing uncertainties, and that the true and scientific value of this wonderful agent in these fields may be definitely ascertained.

Furthermore, the arts and sciences utilize electricity to such an extent that the world looks on in amazement, awaiting eagerly the next electric stride in the amelioration of the conditions which now beset mankind. We are fast approaching the electric age of history, but stand awed in an attempt to contemplate its possibilities.

We will first consider protoplasm as it exists in nature and its associations in the animal organism with reference to the question of electrical conductivity. Demonstrating to my class the circulation of the blood in the web of the frog's foot, the field of vision presented the capillaries with the intermediate substance, composed of numerous variously formed cell-like bodies constituting the tissues of the foot. Histological methods demonstrate that muscle, nerve, adipose, connective or other tissue illustrated in the web which we examined is alike composed of cells or units of protoplasm, vital tissue being therefore a mass of protoplasm.

Protoplasm exists only under certain conditions of environment; it is continually undergoing change (metabolism); its very existence depends upon its property of utilizing certain nutrient substances provided by various means for sustenance, and at the same time the effete products of its vitality must be removed.

We thus have assimilation and disassimilation as conditions which are associated with every protoplasmic particle, from the unicellular

ameboid forms to the multicellular and more complex organisms of the mammalian type. This condition prevails, viz., that protoplasm, whether in the simpler or more complex organisms, receives its pabulum from its immediate environment. The living cell, vegetable or animal, is surrounded with a medium which provides material for assimilation. In the lower forms of life the micro-organism—bacterium, micrococcus, or spore—in aqueous surroundings, secures the oxygen necessary to its existence from the fluid in which it moves. In the higher organisms the circulatory fluid provides a similar condition, supplying to each cell its pabulum, enabling it to fulfill its function as well as retain its vital principle or condition. The microscope enables us to study the morphology of the cell and tissue; to note the varying aspects from the nucleolus to nucleus, to the variously formed tissues of the complete organism. Illustrations of this truth might be represented by the admirable study of the nucleolus and modifications in the living cell by Dr. W. H. Dallinger (Proceedings Royal Microscopical Society), where, in the varying vacuolar manifestations and movements of protoplasmic granules, he demonstrated that the *extra vital* substance was associated with the nucleolus. Another instance would be the work recorded by the embryologist, wherein the manifestations of vital changes from the embryo to various tissues and growth to organs and the fully developed organism is known to the minutest detail, and yet we must deplore that the *vital principle*, the immediate and present cause of all of these changes, is beyond the power of the microscope to reveal.

The microscope might possibly indicate a slightly hyaline appearance to the living cell not present after life has departed, produced by the coagulated state of the protoplasmic mass. Herein lies one of the difficulties met with in the investigation of our subject. Many reports indicate that in the death of animals (death of protoplasm) by powerful electric influence no modification of the tissue is discernible with the microscope.

The composition of the tissue of the body has a marked bearing on the subject we are reviewing. As we are considering the relation of electricity to animal protoplasm, we will take up the more important substances relating to the composition of the tissues making the great bulk of the animal organism. That of greatest fluidity, the blood, has of water about 75 per cent.; a fair percentage of salts, chiefly components of potash and phosphoric acid (C. Schmidt). Muscular tissue, which forms a very large proportion of the bulk of the organism, has a jelly-like consistence.

Yeo says, "the contractile substance of muscle is so soft as to deserve the name fluid rather than solid; it will not drop as a liquid, but its separated parts will flow together again like a half-melted jelly. In this respect it resembles the protoplasm of elementary organisms, the buds from which are so soft that they can unite around foreign bodies, and yet have sufficient consistence to distinguish them from fluid."

The capillaries in the muscle form a fine net-work, which in the active state of the muscle simulates somewhat that condition of congestion produced by the passage of an electric current through living muscle, thus presenting an even greater state of fluidity to this tissue under such conditions. It must be remembered also that all tissue is sustained to a greater or less extent by a circulatory system, and that, even among the more solid portions of the organism, bone has as much as 23 per cent. of water entering into its composition, combined with the salts of the blood circulating in the canaliculi traversing it. The influence of adipose tissue and the epidermis, factors mentioned (Kemmler inquiry) as presenting a marked resistance to the passage of the electric current, must be considered in this connection.

The fat of the body as intermingled with the various tissues of the body is also nourished by a vascular blood supply, and in very few instances (except, possibly, abnormal states) does it present an unbroken barrier to the electric force. In the epidermis, where the greatest resistance is offered, the vascularity produced by the sudoriparous (sweat) ducts, without taking into consideration the capillaries of the papillary derma, would, it seems, be sufficient to eliminate any uncertainty. Furthermore, it is well to note that the animal organism presents a somewhat compact mass, with the exception of the intestinal canal and thoracic cavity in expiration; that outside of this there is practically no break of continuity to the passage of an electric current.

From these generalizations and the statement that fluids with the potassium and sodium salts are better conductors than pure water, it is reasonable to assume that the animal organism, through its great vascularity and chemical composition, presents a medium that may be looked upon as a fairly good conductor of electricity; its real value as a conductor will be considered later. After reviewing a few facts regarding the physics of electricity we will tersely consider the *influence of this agent upon the lower forms of life;* the *chemical or electrolytic changes produced in tissue;* the *conductivity or resistance to the*

passage of the electric force; the *influence of the electric current on sensation*, and finally the *production of death and the utilization of electricity in the execution of the death penalty.*

It may be noted that investigation of these subjects cannot well be carried on without utilizing the microscope. The unfamiliarity of many with the nomenclature employed in the discussion of subjects pertaining to electricity requires a short explanation regarding the terms most frequently used. We assume that all are familiar with the methods of electro-decomposition illustrated practically in electro-plating. The compound fluid, termed an *electrolyte*, being traversed by the electric current of sufficient strength to overcome the chemical affinity existing between its molecules, is broken up into a more elementary state, and the metals, the salts of which were present in the fluid, are deposited at the electrodes. The effect is termed *electrolysis*. That electrode connected with the positive pole is the *anode;* that with the negative pole the *cathode*. Electro-positive elements appear at the negative, and the electro-negative elements at the positive electrode.

Electro-motive force is the power produced by the electrical generator, be it a galvanic cell, a voltaic pile, or dynamo. The electro-motive force of a Daniell standard cell is one *volt*, the electro-motor unit of measurement. In a standard Daniell cell there is a uniform internal resistance to the transmission of the electro-motive force, which is termed an *ohm*, and is the unit of resistance to the passage of the current.

The electrical current passing through a standard Daniell cell has an electro-motive force of one *volt*, and is termed an ampere. Ohm's law is presented by the equation $C = \frac{E}{R}$, or the strength of the current is equal to the electro-motive force divided by the resistance. From this it is seen that the strength of the current passing through an electrolyte, be it a portion of the human body or a decomposable liquid, as in electro-plating, is measured in amperes or fractions of an ampere ; the force of the currents in *volts*, and the resistance of the electrolyte to the passage of the current in ohms. In medical application of electricity the current strength is measured in one-one-thousandths of an ampere or milliamperes, the sensory nervous system being incapable of withstanding strong currents. The milliampere-meter is considered an essential feature of the electro-therapeutical armamentarium, as with it the effects of weak or strong currents may be observed and systematically noted.

The Influence of Electricity Upon the Lower Forms of Life.

Slight electric shocks from a coil (induced current) increase the rapidity of the protoplasmic movements; stronger ones cause tetanic contraction, and numerous and powerful ones produce coagulation. "A constant current causes contraction and imperfect tetanus; and if powerful and long kept up, the positive pole produces in the amœbæ near it the same changes as dilute hydrochloric acid, and the negative pole the same changes as are produced by an alkali, such as potash." Upon infusoria weak electrical currents first quicken the ciliary motion and cause movements of rotation; then produce swelling of the protoplasm, with slower movements, and finally apparent solution of the protoplasm. Moderate currents produce a tetanic contraction of the protoplasm and of the cilia, while the contractile vesicle is unaffected. Strong currents cause liquefaction of the protoplasm. * * * (Pharmacology Therapeutics and Materia Medica, Lauder Brunton, 1885.)

Dr. Klein, in the "Hand Book for the Physiological Laboratory," gives an interesting account of the action of electricity on blood. He explains the method of placing the blood on a slide provided with two poles, when, the cover glass being placed on the slide, the examination is made. According to "Rollet," it is advisable in using electrical discharges that the tinfoil poles should be six millimeters apart. The Leyden jar should have a surface of 500 square centimeters, and give a spark one millimeter long. If, then, the discharges succeed each other at intervals of from three to five minutes the following changes are observed in the colored corpuscles of man: First, the circular discs become slightly crenate. This effect gradually increases; the corpuscles become rosette-shaped, then mulberry-shaped, and, finally, by the acumination of the projections—horse-chesnut-shaped. Later the processes are withdrawn, the blood corpuscles become round and at last pale. The effect on the white blood corpuscles during their movements is to cause them to assume the spheroidal form, but they resume their movement as soon as the current, if not too strong, is discontinued. Under the influence of successive shocks of greater intensity they swell out, their granules exhibiting molecular movement, and finally disappear. Without further consideration of the influence of the electric current upon the lower forms of life, it may be seen that the influence is positive in its character; that we have with the weaker currents an undoubted

electrolysis produced, and with the stronger or a long-continued influence of the current a lowered vitality of the protoplasm.

The blood taken by myself from the temple of William Kemmler, the first man executed by electricity, seven minutes after the current had been turned off, presented marked peculiarities. Fully one-third of the field in many instances exhibited corpuscles ranging from a size approximating the normal to the size of ordinary granules. Protrusion of the protoplasm from the corpuscles was frequently noted. (See Plate.)

The Chemical or Electrolytical Changes in Tissue.

In considering this subject we will omit the consideration of *electrotonous*, a condition produced in nervous and adjacent tissue by the passage of an electric current through it, and which has been quite fully considered by physiologists.

As to the influence of the faradic current (alternating current) upon an electrolyte, testimony seems to favor the view that electrolysis is produced, although not in the same degree as with the galvanic current. (Foot-note, "London Telegraph Journal," "Electrolysis by alternating current of dynamo machines.")

The galvanic current will produce the following action: At the positive pole hydrogen gas will be generated; at the negative, an alkalinity in the fluid will be produced. The blood, filling a vascular growth, if a sufficiently powerful current be used, will gradually coagulate. Just what the nature of the effect of the continuous current upon the internodal fluids and tissues of the body may be, it is difficult to state, but the opinion of leading medical electricians is almost unanimous in favor of a change taking place. Amory, in his work on Electrolysis (page 127), says: "There are four methods by which electricity can be supposed to interfere with interstitial nutrition, and, in consequence of the interference, destroy the life of the cells, viz: 1st. By producing a true decomposition of the chemical compounds, upon whose combination the integrity of the living structure depends. 2nd. By interfering with the natural processes of cell segmentation, by which their proliferation and increase is effected; this interference would thus prevent the repair and multiplication of the cells, whose living functions are essential to the growth of the living tissues. 3rd. By promoting a movement of the mass of fluid in the living tissues towards the negative electrode, and thus interfering with the constructive metabolisms upon which interstitial nutrition depends. 4th. The acid and alkaline reactions at

the positive and negative electrodes respectively, from which a caustic action upon the tissues is effected through contact of these two different chemical reactions." Amory in these statements is endeavoring to find a rational cause for the destruction of abnormal growths.

As to special modification of tissue, in a discussion held before the New York Academy of Medicine November 27, 1889, Dr. A. H. Buchmaster recited the following experiments: The heart of an anæsthetized dog was exposed and a current of forty milliamperes made to traverse a portion of the ventricle. A piece of the ventricle in the direct line of the current was excised, and another some little distance from the direct influence of the current. When examined under the microscope the piece from the direct line of the current showed that the striæ had become markedly granular, while the piece outside of the direct line of the current preserved the muscle cells unaltered. It was stated that this was the first evidence of absolute molecular disintegration of the living cells by the interpolar action of the galvanic current where such process is confined to the cells.

Some deductions from the discussion by the editor of the Journal are noted as follows: "Electricity will relieve the pain due to the pressure and sympathetic disturbances in the majority of fibroid tumors in from one to six applications treated by that agent. Hemorrhage due to fibroids can be relieved by the positive galvano-caustique applications of electricity in all cases in which a sufficiently concentrated dose can be applied to a greater portion of the endometrium."

A large percentage of tumors of enormous size can be checked in growth and often reduced in size by an intelligent and persistent application of this agent, while tumors of medium and smaller size can be markedly reduced, and in a few instances be made totally to disappear. The majority of patients while under this form of treatment improve rapidly in general health from the characteristic tonic effect excited upon the whole system. It is said that the general tone of this discussion was practically free from the exuberant and unsafe positiveness of the enthusiastic hobbyist.

Dr. A. D. Rockwell speaks in an article published in the January number of the Journal of Electro-Therapeutics of the tonic effect of the electric current. Speaking of the faradic current he states that every electro-therapeutist is taught that even the induced current exerts some other and more subtle influence upon the nerves themselves, for by no purely mechanical means can we account for the

numerous phenomena that follow its use in diseased conditions. It gives passive exercise to the muscles; it promotes and renders more natural the processes of excretion and secretion; it corrects circulatory disturbances—in a word, it imparts tone, strength to both nerve and muscle. The chemical or electrolytic influences associated with electrical action are practically confined to galvanism. He says it is undoubtedly true that some electrolytic action occurs in all ordinary applications of galvanism to the body, whatever form of electrode is used. A distinction has been made between electrolysis and galvano-chemical cauterization. The one is a disintegration and separation of the constituent elements of organized structure. The other produces its effects by means of the acid and alkalies that are liberated at either pole by electrolytic action.

Dr. M. Allen Starr, in a paper read before the New York Academy of Medicine March 21, 1889, concludes that "the constant galvanic current could produce chemical changes which aided nutrition or destroyed tissue, according to the strength employed. The constant galvanic current could transfer medicines in the body from without (cataphoresis). The interrupted galvanic or faradic current could excite various organs to functional activity."

Dr. Frederick Peterson, of New York, from a series of experiments on cataphoresis with, principally, cocaine and aconitine, concluded (see Dr. A. D. Rockwell's article in Medical Annual) that with the former or two combined a deep anæsthesia may be produced in conjunction with the anode. The anæsthesia may be made rapid with the use of strong currents or slowly produced with a current imperceptable to the patient.

Upon this subject we need not dwell further. Catalysis takes place in living tissue. Its precise nature is not understood. Cataphoresis, also a proof of catalysis, appears to be a clearly demonstrated fact.

The Resistance of Tissues to the Passage of the Electrical Current.

In the application of electricity in medicine the electrode applied to the body is usually a sponge saturated with fluid and connected with the metal portion of the electrode. The greatest resistance is at the point of contact with the body, and the character of the fluid used has much to do with overcoming the resistance. If the resistance should be considerable a cautery effect would be produced if the current be kept up a sufficient time, and series of burns might follow with sufficient electro-motive force. From a paper in "The Electrical World" of May 26, 1890, the average of a series of re-

sistances on the human body, made by Dr. W. T. Stone, are as follows: Foot to foot resistance of three adults gave 935 ohms. The average resistance from foot to hand of same parties gave 1,126 ohms. These, from the context of report, are considered continuous current resistances.

In same paper experiments conducted by Mr. Wm. Lant Carpenter are interesting as showing the decreased resistance obtained by a steady continuance of application. Resistance taken from foot to foot with dry skin was 1,030 ohms; with salt and water to saturate electrode, in 1 minute, 4,300 ohms; in 10 minutes, 1,900 ohms; 20 minutes, 1,540 ohms; 30 minutes, 1,400 ohms; 40 minutes, 1,250 ohms; 50 minutes, 1,200 ohms; 60 minutes, 1,190 ohms to 1,200 ohms.

In the same paper, entitled "Alternating *vs.* Continuous Currents in Relation to the Human Body," by H. Newmann Lawrence and Arthur Harries, the authors present three series of measurements on ten adults of ages from 21 to 40 years. The electrodes, each of 50 square centimeters area, were used, the extended palms being placed on or grasping the electrodes. The conditions which might occur in accidental grasping of electrodes of conductors from dynamo currents were simulated as near as possible. The averages of the three tables given were as follows:

TABLE No. 1.

Resistance to continuous currents:

Dry hands.	Moistened with distilled water.	Moistened with salt water.
38,140 ohms.	15,250 ohms.	9,557 ohms.

TABLE No. 2.

Resistance to alternating currents:

Dry hands.	Moistened with distilled water.	Moistened with salt water.
4,155 ohms.	1,722 ohms.	1,365 ohms.

TABLE No. 3.

Resistance to continuous currents:

Dry hands.	Moist hands.
14,475 ohms.	9,750 ohms.

Resistance to alternating currents:

Dry hands.	Moist hands.
1,740 ohms.	1,437 ohms.

One feature is prominent in these results, viz., that the resistance obtained by the alternating curren' is very much less than that obtained with the continuous current.

Mr. Thomas A. Edison instituted a series of experiments to ascertain the resistance of the human body to the passage of the electric force; 259 male persons, of various ages, weighing from 68 to 192 pounds, measured between the hands immersed to the wrists in caustic potash, aqueous solution, of density 1.1, gave the following results: Mean of all resistance, 986 ohms.

The deductions drawn from this extended series of measurements were as follows: The resistance of a man's body, taken between the hands, varies with *the solution* employed for immersion and the area of skin immersed, together with the superficial condition of the epidermis; that with a fixed solution, immersion, and area the resistance does not vary to any appreciable extent with the battery power used in the measurement, when the effects of polarization are eliminated; that with the K H O solution used, as given above, the resistance at about 30 seconds immersion is about 1,000 ohms. Why the resistance with the alternating current was not used is not stated. These experiments were brought about through the controversy on electro-execution, and from the great difference in resistance demonstrated by the English gentleman referred to previously between the continuous and alternating current it would have been of great interest to have compared the results in so extended a series of measurements. Few who use electricity in medical practice will question the following statements of Dr. A. D. Rockwell, taken from "Kemmler inquiry," that the resistance falls more rapidly when a low potential is used, and that the fall of the resistance, taking men ordinarily, would range between 1,200 and 400 ohms, and that this fall of resistance would be almost instantaneous; that after the current has once overcome the resistance, the resistance is gradually lessened until about the minimum resistance is reached, when it remains nearly stationary under a constant potentiality.

The Influence of Electricity on Sensation.

Any physician practically using galvanism in his medical work will find that 20 milliamperes will be generally painful to his patients. In fact, frequently a less powerful current will be objected to. It depends to a great extent upon the portion of the body operated upon. If a mucous membrane, even 5 to 10 milliamperes may prove very painful. As to the comparison between the painful effects of

the continuous and alternating currents, a paper read before the Institution of Electrical Engineers, London, England, March 27, 1890, throws some light. (See "Electrical World," May 26, 1890.) The writers adopt 10 milliamperes as the maximum continuous current which may be passed through the body without producing unpleasant sensations. With alternating currents they found a great difference, inasmuch as before a single milliampere was registered their patients complained that the current was too strong and practically unbearable. In the course of their investigations they found but few persons who could bear with comfort one milliampere of alternating current. From their experiments upon ten persons they found that one and seven-tenths milliamperes (1.7) of alternating current was, on the average, all that could be borne without discomfort. Beyond that point violent muscular contraction, rendering relaxation of grasp first difficult and then impossible, produces distinct pain, which agitates the whole body. They state as their conclusions that the human body can bear with ease at least five times as much of continuous current strength as of alternating current strength. Dosage of electricity is somewhat similar in results to that of many dangerous drugs. If the dose is insufficient to kill, the result, owing to the influence on the system, may range from a slight to a most serious effect. Where the powerful doses of electricity have been received and the party survived, it is to be expected that recovery will be associated with painful sensations, which may vary greatly in degree. In railroad disasters, for instance, we have surgical shock, from that degree which produces momentary paralysis to that which produces apparent instantaneous death. This applies to many cases of recovery from powerful shocks of electricity. Testimony is quite uniform to the effect that no sensation was experienced by the patient at the time of stroke. This can only be accounted for by the assumption that the electric influence is so rapid in action that sensation cannot be transmitted to the brain centers before they are paralysed by the electric force.

I attended a meeting of the National Electric Light Association, at Niagara Falls, New York, August, 1889, to listen to an address opposing electro-execution. I went as a spectator, but was called upon to address the meeting. Among other statements regarding death by electricity, I said from my own demonstrations I could not help but come to the conclusion that no other agent we had at our command would execute criminals with such rapidity and without question of pain. I was then cross-questioned right and left, as I

found I had struck a chord entirely out of unison with the views of the great majority of the members of the convention. This question: "I want to ask Dr. Fell if these several hundred deaths (referring to accidental deaths from electricity) were painless, and if on these points he rests his claim?" I answered by stating that Wheatstone had demonstrated that the electric current or force was manifested or passed at the rate of 280,000 miles per second of time. Further, that the nerve current or force was manifested or passed at the rate of about 111 feet per second, or some 2,500 or more times less rapidly; that when an electric current passed through the body it was hardly possible that the nerve current could overtake it even (allowing for difference in probable speed in conductivity of agent) or respond so as to produce a sensory impression on the brain centers, and that therefore death by a powerful electric shock, properly applied, would be painless. The following answer was made by Professor Anthony: "I have only a word or two to say. Dr. Fell made the remark that it was well known that Wheatstone demonstrated that the velocity of electricity was 280,000 miles per second. All of us know that such experiments were unreliable, and that it is now perfectly well understood that it was not the velocity of electricity at all, but simply the time required for those wires to be charged, and for a spark to leap across the gap between the two wires. The velocity with which electricity passes over any given conductor is not known, and we know that the velocity depends upon a thousand things. In the first place, it depends upon the conductivity of the conductor. In the second place, upon the amount of pressure or potential, and upon many other things. The fact is that upon the nerves of the human body the velocity of the electrical current is known to be immensely less than it is in a metallic wire. In a wet string the velocity of the current, in passing over even a space of a few feet, is readily measurable, requiring quite a large fraction of a second to pass over a distance of a few feet. I merely speak of this matter that it may go upon record, if these discussions are to be reported, that this question of the velocity of electricity cannot settle the point as to whether the death by electricity would be painless or not." I think it is generally understood that the term current, as applied, refers to electric force, and whether it takes a certain time to charge a conductor or to have the electric force or current manifested under the conditions mentioned is the same thing.

The testimony of many who have received powerful electric strokes and recovered is almost unanimous regarding the entire absence of

sensation. In all cases where the cerebrum has been influenced this question may be decided in favor of entire loss of sensation. Had the sensory apparatus of the body time to act under these shocks, the recipient would undoubtedly be cognizant of it after recovery. I will refer to an experiment with the Kemmler chair later, having a bearing on this question of sensation.

The Production of Death and the Utilization of Electricity in the Execution of the Death Penalty.

The controversy occasioned by the passage of the electro-execution law by the State of New York has a direct bearing upon our subject. I propose to give tersely its history and my connection with it. The following report of experiments made by myself is copied from that of the commission appointed by Governor Hill, of New York State, to inquire into the most humane method of executing criminals. This commission consisted of Elbridge T. Gerry, Dr. A. P. Southwick, and Matthew Hale:

"In the month of July, 1887, there was conducted a series of experiments calculated to throw considerable light upon the powerful and injurious effect of electricity upon animal life. The authorities of the city of Buffalo, N. Y., had determined to rid the city of the numerous curs roaming the streets. To reduce their sufferings to a minimum, the agent of the Society for the Prevention of Cruelty to Animals recommended that electricity be applied as the death-dealing agent. The experiments were conducted at the improvised dog pond prepared at old police headquarters.

The canines were quartered in one room; adjoining this was an entry which communicated with a third room, in which the electrical apparatus was located. This consisted of a common pine box lined with zinc, and connected with one pole of the electric-light current for that portion of the city. When in use the box was partially filled with water. Connected with the electric-light wire, representing the other pole, was an ordinary dog muzzle, supplied with an iron or copper bit, which was inserted into the mouth of the canine. The animal being placed in the box, the switch making the circuit was turned, causing the apparent instantaneous death of the animal. Only in exceptional cases were any movements noted after the current was made. The result obtained by experiments conducted in this manner leaves the subject just where public opinion would place it, viz., "that electricity will kill quickly." However, to ascertain how quickly and thoroughly, requires further demonstration.

The heart may rightfully be considered the center of function, and in the execution of criminals by the legalized hanging process, is always examined to ascertain when death ensues. In favorable cases it is known that the heart may beat from six to ten minutes, and in some cases it has been known to beat from fifteen to thirty minutes after the drop. For the purpose of ascertaining the effect of the electric-light current on the action of the heart, the operation of opening the thorax of an animal under forced respiration was made. With the operation satisfactorily performed, the heart and lungs may be observed in action, viz., the heart beating and the lungs contracting and expanding as in life.

While the operation is not new to physiologists, still the effects upon the movements of the exposed heart by the passage of an electrical current which might be applied in the execution of criminals I do not believe has been frequently noted or the operation often, if ever before, performed. That the ordinary electric-light current used in these experiments is sufficient to cause instantaneous death of a human being is inferred from the many accidental deaths produced by such means. To witness the effect produced upon the heart in action is a demonstration which cannot be questioned, and offers a positive answer to what may have been inferential. To those favoring electricity as the proper agent in the execution of criminals, a demonstration of this character serves to make them more positive and less liable to be influenced by those whose investigations into the subject have been only superficial. Those opposed to it from the standpoint of uncertainty of action, it leaves without a foundation upon which to base their opinion. Prior to these experiments I held the view that electricity might prove the best agent for executing criminals; after they were made, I enthusiastically supported it as the only agent which this age had any right to use for this purpose.

But to refer to the experiments: A fair-sized dog was placed under the influence of chloroform, an incision was made in the trachea, in which a tube connecting with foot bellows and supplied with suitable valve for respiratory purposes was attached. Respirations were then kept up by these artificial means. The chest walls (thorax) were then removed, so that the heart and lungs were exposed to view; the dog was then placed in the zinc-lined box, the muzzle put on, the forced respirations kept up until just before the current was made. The heart was beating as in life, but the instant the circuit was made it ceased its action and became a mere mass of quivering flesh; not

the least resemblance to a rhythmical movement was observed after the current was made. Many citizens present at the operation can testify to the above; in fact, the demonstration as to suddenness of stoppage of the heart exceeded all anticipation. The interference with all function was electrically instantaneous; death ensued from electric shock; the ordinary conditions of dying were absent; nothing could be more sudden.

This first experiment, although eminently satisfactory in its results, was made under conditions the most unsatisfactory. The rooms were full of men hurrying to and fro; the dogs were being led to their fate, and no suitable place was provided to operate. This and observations connected with another series of investigations led to a second demonstration, which was made under more favorable conditions, at the electric-light works on Wilkeson street, Buffalo. This operation was conducted with greater care. Instead of the muzzle, with the bit attached to make one pole of the circuit, a piece of wire line was placed in the mouth of the dog and wound around the nose. The zinc box was used as before; chloroform narcosis was produced and the thoracic walls removed. The heart was beating rhythmically. On making the circuit it instantly ceased to beat. The current was quickly turned off and forced respiration kept up with the view of bringing the heart again into action. This was entirely unsuccessful. The result demonstrates that if the current used is sufficiently powerful attempts at resuscitation in the case of a criminal executed by electricity would certainly fail. In this second experiment it was also noticed that an attempt to respire was made by the animal after the current was turned on. This undoubtedly indicated that the respiratory center in the brain (medulla) had not completely lost its susceptibility to impressions, and that, through the want of oxygen in the blood and center noted, the effort to breathe was formulated. This has an important bearing upon the apparatus to be used in executions, inasmuch as it indicates that the poles should be arranged to pass the current through the centers of function in the brain. Upon physiological grounds, also, this is indicated. Even without this refinement of precision in the apparatus, as has been shown in this last experiment, where the current was not passed directly through the functional brain centers, the sudden stoppage of the heart would indicate that electricity offers the most rapid agent in producing death that we have at our command. The mere estimate of the difference in the speed of the electric compared with the nervous current would further show that our senses could not

interpret or apprehend the passage, or that death produced by such means would be absolutely painless to the culprit. From observations which are generally accepted, it may be stated that nervous force travels at a rate of from one to three hundred feet per second, while the electric passes at a rate of no less than two hundred thousand feet per second, or about one thousand times as rapid. From these observations the following deductions may be drawn:

"First. That death produced by a sufficiently powerful electric current is the most rapid and humane produced by any agent at our command.

"Second. That resuscitation, after the passage of such a current through the body and functional centers of the brain, is impossible.

"Third. That the apparatus to be used should be arranged to permit the current to pass through the centers of function and intelligence in the brain."

When this report was prepared it was understood that it was to go before the Legislature of the State of New York. It was the only record of actual demonstration in the report of the commission bearing upon the subject in question; that it was influential in the passage of the electro-execution bill goes without the saying. Since the Kemmler execution I am more than satisfied with the truth of my conclusions. The report has been criticised as not covering electrical measurements. I was limited in apparatus, and accomplished as much as was possible with the means at my command.

To the physiologist, accustomed to demonstrate the action of the heart and lungs in life, it is noticeable that the heart does not spontaneously cease its rhythmical movements. It dies slowly, the movement becoming more and more labored until it ceases. To all who witnessed the experiments just reported, the sudden stoppage of the heart appeared to indicate a special influence of the current on that viscus. Subsequent experiments by many experimenters have proven the correctness of these conclusions.

The next series of experiments took place under the direction of Harold P. Brown, Esq., at the Columbia College School of Mines, New York city. A large dog was given 300 volts pressure, and then 1,000 volts of continuous current, without injury; but 300 volts of alternating current caused intant death. August 3, 1888, at the same institution, another series of experiments were made by Dr. Cyrus Edson and Dr. Charles F. Roberts, of the New York board of health. The results of these observations, made to determine the danger of the alternating current, were as follows: A dog weighing 61 pounds,

in good condition ; resistance from left front leg to right hind leg, 14,000 ohms ; two hundred and seventy-two volts, with 288 alternations per second, killed the animal ; heart ceased breathing in 90 seconds ; dog immediately dissected by Doctors Roberts and Peterson ; sections of sciatic and pneumonogastric nerves, muscular fibres of lungs and diaphragm examined microscopically ; no change in the structure observed.

A second powerful dog, weighing 91 pounds, was used ; resistance 8,000 ohms ; alternating current, 340 volts, applied for five seconds ; dog silent during continuance of the current. For eight seconds after opening the current the dog howled and gasped from mechanical action, but was unconscious from the instant the current was applied ; death in two minutes and fifty seconds.

The third dog, weighing 53 pounds ; resistance, 30,000 ohms ; 220 volts applied for five seconds. The result was not fatal for four minutes afterwards ; dog rigid and motionless during continuance of the shock. The same current continued for 30 seconds, the voltage rising to 234 volts ; dog died without sound or struggle. In this series of experiments the physicians present expressed the opinion that the dogs had a higher vitality, and that the current that killed a dog would be fatal to a man under the same conditions. It was their opinion that all of these deaths were painless, as the nerves were probably destroyed in less time than that required to admit the nervous impression to the brain.

As the heaviest of several dogs killed weighed but 91 pounds, it was claimed that the experiments could not be regarded as a criterion for the effect of the current upon a human being, and a further series of experiments were conducted by Harold P. Brown at the Edison laboratory. A strong and vigorous horse, weighing 1,230 pounds, and two calves, weighing respectively 124 and 145 pounds, were killed by the alternating current at 700, 770, and 750 volts. In all of these instances death is said to have been instantaneous and painless. A report of a committee of the Medical Legal Society recommended that the alternating current be used for the execution of criminals. The details that are interesting in this report are as follows : Regarding the application of the death current to man, it is stated that the average resistance of the human body is 2,500 ohms. In the application of the current for executions, the recumbent or sitting position was suggested. It was recommended that one electrode might be placed in contact with the head, and one electrode upon the spine between the shoulders, or, as I had previously reported

on the conclusion of my first experiments, the current should be made to pass through the functional centers of the brain

A dynamo, generating the electro-motive force of at least 3,000 volts, should be employed, and a current used with a potential between 1,000 and 1,500 volts, according to the resistance of the criminal. In one of their experiments, upon the suggestion that the current should be applied through wristlet electrodes, upon, I presume, the theory that death would be as instantaneous as when applied to the brain centers, and so as to include the heart, they applied the current to the four legs of a horse, but found that the method was not nearly as effective as when applied to the head and back. These experiments are recorded in the appendix to the testimony (Kemmler inquiry) before the court of appeals, State of New York.

The next series of experiments became of intense practical interest, as the dynamo used was that provided by the State of New York for the execution of criminals at Auburn prison, and with which it was thought the first electro-execution would be produced. As I took a prominent part in this and a subsequent experiment at the same place, I will naturally be able to give a more detailed account than those with which I was unacquainted. The commission appointed to examine the apparatus preparatory to final purchase by the State consisted of Carlos F. Macdonald, M. D.; A. D. Rockwell, M. D., and Louis H. Landy, Ph. D. In addition, Gen. Austin Lathrop, superintendent of State prisons; Harold P. Brown, who furnished the apparatus; Mr. Charles F. Durston, warden of Auburn prison, and myself were also present.

From the report of the commission I gather the following facts relating to the power of the dynamo: The commercial voltage, 1,680; the mean voltage, 1,512; the maximum voltage, 2,376; speed of dynamo voltage, 1,700; speed of exciter, 2,700. In the alternating dynamo the maximum of the electro-motive force obtained in the rapidly changing alternations, or the mean of them, may be taken as the electro-motive force of the dynamo; hence the varying voltages given as above by the commission. Regarding the difference between the alternating current and continuous current, we may note in explanation that the continuous represents a steady electro-motive force in one direction, as in the galvanic current, while the alternating current, simulating the faradic or induced current at each alternation, proceeds from zero to the maximum and recedes to zero, and repeats this in the opposite direction. The definition given by the committee of the commercial voltage of an alter-

nating dynamo is as follows: "Say fifty volts is such an alternating voltage as will, upon an incandescent lamp or Cardew voltmeter, produce the same light and heat effects as fifty volts in the case of a continuous current."

The commission had made their tests; wires were carried to a shed adjoining the prison. An old but vigorous horse, weighing some 1,200 pounds, had been secured. One electrode was secured above his eyes with cords, and the other was also attached above the knee-joint of left hind leg. The electrodes were of copper plate, with cotton waste attached; the cotton was saturated with warm water, which was poured over them after being attached. One noticeable feature on this occasion was the anxiety of all present regarding the ontcome of the experiment. All the gentlemen present had witnessed the death of the animals by electricity previously, and believed in the efficacy of the agent. However, this was the first experiment with the dynamo which was supposed would soon be used in the execution of a human being. The experiment being made upon a large horse, a slight failure would not, of course, be so serious a matter, as the resistance of a horse with the current passing through the whole length of the animal's body would naturally be very much greater than that which would be presented in the body of any culprit; but it would have dampened the ardor of all interested in a successful result. Noticing a diffidence on the part of the gentlemen present in taking active part in the experiment, I took off my coat, donned my physiological laboratory apron, and went to work. I was requested to turn the switch, and all breathlessly watched with interest the result of the shock. The horse by this time was standing quietly in one corner of the shed, undisturbed as to what was going on about him. When it was ascertained that the dynamo was in full operation, I took my stand upon the box, and, with my hand on the switch, watched the horse as I made the connection. He immediately stiffened out and fell to the ground dead. The current was kept up twenty seconds. There was not, in fact, a move on the part of the animal. The moment the current was turned off, with several assistants I removed the electrodes attached to the animal, made a slit between the ribs, in which I thrust my hand, with the idea of detecting any heart action. There was none; death had been instantaneous. A good-sized calf was then taken and the electrodes applied to the head and spine, as I suggested. I turned on the current, and, as before, the animal was instantly dead. The current was turned off, having been acting ten seconds; elec-

trodes were removed. I made tracheotomy and applied *forced respiration* with the same instrument with which I have saved six human lives. It was kept up for half an hour, and at no time was there any heart response. I desire to state that this animal was placed under the best condition known to medical science to live after the shock had been given. I made this experiment, not with any belief that the animal which had received such a powerful electrical shock could be revived, but merely to satisfy those who had been influenced by the ignorant statements made in some portions of the "Kemmler inquiry," to the effect that animals which had received a large dose of electricity might be revived if placed in the ground for a period of time until the electricity, said to have saturated them, had been drawn from them by the moist earth.

These experiments, as all the others I witnessed, presented no feature of uncertainty; no sound or cry was made by the animals, and, as I had formerly advocated the use of electricity as a death-dealing agent, I could not but feel satisfied with the results.

And now comes the question of the method of application of this agent to the execution of a human being. At the time these experiments were made the electro-execution plant at Auburn was in a decidedly chaotic state. Considerable labor had yet to be expended to place it in a satisfactory condition.

THE KEMMLER CHAIR.

No chair suitable or accepted by those in authority for the purpose had been prepared. One illy adapted to the purpose was lying in the vaults of the prison, known as the Harold P. Brown chair. As the execution of Kemmler had been ordered by the courts, it was natural that those in authority should feel the necessity of prompt action. Following the above experiments, I explained to Gen. Austin Lathrop, superintendent of State prisons, my views relating to the features of the chair to be used. At his request I subsequently made drawings and specifications, and was requested to have a chair made according to my views. I carried out the idea I formerly expressed, viz., that the current should be made to pass through the centers of function and intelligence in the brain, etc. One electrode was placed over the cerebrum; the other against the spine, in the dorsal or lumbar region.

The dissemination of the current with electrodes thus applied would include the heart and produce the greatest density in neck,

including the region of the medulla oblongata. February 12, 1889, the chair was shipped to the warden of Auburn prison, Mr. Charles F. Durston.

At the request of General Lathrop I had kept the manufacture of the chair a secret, so that no notice had appeared regarding it. It resembles an ordinary heavy oak arm-chair, with perforated, wooden seat, the cross-pieces at lower portion of back removed to give room for spinal electrode. Two upright pieces at the back of chair permit a third upright piece to move between them. This carries a strong arm at upper end, which projects forward over the head of the culprit and carries the head electrode, which may be secured at any point by simply turning a binding screw, which secures the upright piece supporting the electrode; by this means the chair can be used for a large or small individual. A foot-rest, which can be pulled out from under the seat of the chair, has a cross or body piece provided to prevent the feet or body from sliding forward when a current is applied and rigor of the muscles ensues. This foot-rest was not used at the execution, and, from the experience obtained, is not needed. Without this, however, the straps supplied secure the body from moving. Straps are provided to secure the arms and limbs from movement. One passes around chest, holding the upper portion of the body from moving forward. A combination chin and forehead mask prevents any movement of the head.

The spinal electrode is held in place by a strap which is attached to each arm of the chair; another strap secures it to the criminal, while an abdominal strap pulls the body backward against it. The head electrode is provided with a spring which takes up any downward movement of the head if it should occur, and, with the spring of the rubber cups forming them, the combination effectually prevents any possibility of the culprit executing a sudden movement to escape contact with the electrodes. The electrodes are circular, four inches in diameter. Each one is surrounded by a rubber cup, with the edges of its sides flattened so as to fit closely the body or head. The electrodes are brass perforated plates covered with sponge, and secured to the large wire which passes through the rubber cups to be connected with the dynamo wires. When the electrodes are in place and properly arranged the edges of the cups press against the head and body of the culprit. Openings are provided so that the saturating fluid may be applied with a long rubber pipette, with large bulb provided for the purpose, at any moment previous or during the passage of the current. The spinal electrode can easily be attached

to the criminal before he is seated in the chair, and connected with the dynamo wires later, if desired.

In a letter to General Lathrop describing the chair, I stated as my belief that it would accomplish the work for which it was constructed, *if sufficient electro-motive force was used,* and in such a manner as to take away from public executions the horrors which frequently attended them. Since the execution of Kemmler I am more than satisfied of the truth of this statement. In my laboratory I had passed a galvanic current through the electrodes when applied to individuals who had allowed me to experiment with them, and thus demonstrated that the method devised for attachment of electrodes would offer a minimum of resistance when suitable fluids were used. In these cases an instantaneous flash of light was noted on the make and break of the current. With five volts electro-motive force and a current of five milliamperes a flash would be produced with the most rapid making and breaking of the current, demonstrating (so far as the senses could appreciate) instantaneous passage of the current through the body and indicating in degree the rapidity of death by this method. By accidental contact 10 to 12 volts were passed through a young gentleman in the chair; he was stunned, almost rendered unconscious, and quite thoroughly frightened. When it is considered that the current as applied passes through all the vital centers of the body, beginning at the cerebrum, the center of intelligence, and taking in the cerebellum, medulla oblongata, heart, and lungs by diffusion, and spinal chord, the effect of the powerful current of a dynamo upon a culprit may be appreciated.

I wish to state it as my belief that a current with 50 or 100 volts e. m. f., occasionally alternated, passed through the body in the course provided by the Kemmler chair is more than a human being could stand for any length of time. The remarkable statements of men living after vital portions of the body had received 800 to 1,000 alternating voltage I do not credit for a moment.

In sequential order the next experiment took place at Auburn, New York, during the week beginning April 28, 1889, when Kemmler had been sentenced to die according to the new law. The witnesses to this proposed execution, as is well known, through legal processes, did not see Kemmler die. There was a natural desire to see the power of the current on an animal, and Mr. C. F. Durston procured a good-sized calf for this purpose. I took entire charge of this experiment, and know from experience that the attachment of electrodes weighted down with a long, heavy wire to the head and

spine of a calf is no easy task. The calf was overcome and quietly lying on the floor when Mr. Durston (at my request) turned on the current of about 1,200 volts e. m. f., instant rigidity of the animal resulted. In ten seconds I gave the signal to turn off the current; the rigidity passed away; the animal had been instantly killed. Previous to the application of the current I secured some blood from the animal; about an hour after I also took some. Microscopical examination revealed that the corpuscles taken subsequent to death were markedly crenated, which, on comparison with blood taken from a calf killed by a butcher, I believe, however, to be a post-mortem change.

As by experiments on the lower animals we can only arrive at conclusions regarding the death-dealing influence of electricity, I wish to refer to the work of Dr. Edward Tatum, of Yonkers, New York, made at the University of Pennsylvania.

Dogs were the only animals used. Experiments were arranged for the purpose of ascertaining how definite a relation might exist between density of current and fatal result. The procedure was as follows in the case of each dog: With the closure of a current that was not expected to be fatal, and then to follow that with closures of successively increasing strength until the heart was arrested. The duration of each closure was one second; and a subsequent dose was not given until the heart and respiration were apparently restored. The electrodes were flexible frames of fine copper wire, covered with a thick coating of absorbent cotton, and were wet with weak salt solution. A round one, about two inches in diameter, was bound on the forehead, and a rectangular one, one and one-half by six inches, was bound upon the inner aspect of the right thigh, as close to the body as possible.

In a letter from Dr. Tatum, of March 15, 1890, in response to an inquiry, he says:

"It is understood, of course, that my results are in strictness only applicable to dogs.

"These results are, in brief, that with currents of between one and three amperes the heart is distinctly stopped before the current has produced any other discoverable lesion; and this, even after division in the neck of both pneumogastrics, or the profound poisoning of their terminations in the heart substance by curare or atropine, or even after the chest wall has been opened. The stronger the current the more distinctly and independently is the separate action of the heart recognizable, and the more unavoidable is the conclusion that

the result flows from a direct action on the heart substance of that portion of the current which actually traverses it.

"Currents of less strength than about one ampere may require from one to many seconds before the heart is arrested. As this interval is lengthened the interference with pulmonary respiration assumes greater importance, until a point is reached when it may be said that death results from simple suffocation. These results were obtained with the sort of currents that are used commercially, namely, continuous currents, as well as very rapidly alternating ones.

"The strongest current I have applied to a dog was about three amperes, requiring a pressure with carefully applied electrodes of between 900 and 1,000 volts, and consuming about four actual horse-power. Such a current has killed when continued for only one-eighth part of a second. The maximum volume of mixed gases that this current could liberate in that time, under the most favorable circumstances, in a sulphuric acid voltmeter, would be less than one-fifth of a cubic centimeter (at the temperature of the body). This power is equivalent to the liberation of heat of 0.71 kilogram degrees, centigrade, in one second, and in one-eighth second would be able to raise the temperature of a 15-kilo dog about the one hundred and fiftieth part of one degree centigrade."

In a letter dated May 27, 1890, Dr. Tatum refers to his article in the *Electrical World*, and refers to certain facts which they seem to prove, as follows—some of them, it will be noted, have an important bearing on the Kemmler case:

"1st. In only three of the twenty-four dogs killed did the heart fail to be arrested distinctly before respiration. In these three no priority could be assigned to the failure of either function. But in the twenty-one other dogs effective respiration survived the final heart arrest. It often began with normal or slightly exaggerated force and good rhythm, then died out more or less gradually, but with no final convulsions. Fair inspirations were recorded in several cases as long as four or five minutes after a dose which had lasted only one second, but after which the heart had not executed a single beat that could be detected.

"2nd. Contrary to what I believe has been the general impression, as well as my own, the two cases in which I used currents with 120 reversals per second seem to indicate that if fatal results are at all dependent upon the rapidity of alternation, 120 reversals per second are slightly more mischievous than 300.

"3rd. Alternating currents, as has been long supposed (though on

what seemed to be insufficient evidence), can, for a given time and mode of application, bring about a fatal result with only a fraction of the electrical output required by continuous currents; but even here a certain respectable density of current is required, for the least neck density of alternating current that proved fatal was somewhat greater than one-fifth of the least fatal density with continuous currents.

"4th. The noteworthy fact was developed that under ether, this difference in fatal power between continuous and alternating currents either entirely disappears (4 dogs) or is at least conspicuously lessened (2 dogs)."

The Doctor then attempts to account for the difference in fatal power under ether in these words: "It seems to be both a necessary and an adequate explanation to refer it entirely to the well-known superiority of interrupted or alternating currents as nerve excitants. This property normally enables alternating currents to add to whatever direct physical action they may have in crippling the heart muscle, all the physiological energy of the cardio-inhibitory nervous mechanism; but, of course, it loses its importance just in proportion as the nervous control of the heart is weakened by ether.

"The fact to be emphasized is that this superiority of alternating currents is not owing to any kind of lesion or paralysis or exhaustion of any part of the nervous mechanism, but rather to the calling into action of a truly physiological function, and depends for its manifestations upon the integrity of this mechanism."

He says: "In spite of the strong general opinion against my position, I had been able, until this last series of experiments was undertaken, to believe that there was no important difference between the fatal powers of continuous and alternating currents (when either effective voltage or effective current was considered); that the modes of action were identical, and that therefore I had only one sort of death to account for. This happened because when I had originally determined that continuous and alternating currents were of equal power under ether, and that continuous currents were not influenced by ether, I had falsely inferred that the effects of alternating currents were equally independent."

The experiments discussed in the Doctor's article in the *New York Medical Journal* of February 22, 1890, "seemed to show clearly enough that, under the conditions there noted, death was not caused by any sort of tissue lesion outside the heart; but these ether experiments proved that, with normal dogs and alternating currents, no lesion

whatever can be taken into account; for under ether dogs can tolerate without injury currents three or four times as great as have ever been survived without ether; and it would be absurd to suppose that ether could protect any tissue against physical lesion from alternating currents, so as to reduce their power exactly to that of continuous currents, and yet have no effect on the action of continuous currents.

In one of these experiments under ether 1.05 ampere alternating current was passed through a dog from forehead to thigh (after four other applications gradually approaching this in strength). This is just three times as strong as the strongest current that I have yet used in killing a dog without ether. It is four and three-quarters times as strong as any dog has survived without ether; yet one hour after this surprisingly large dose the animal, being fairly recovered from the ether, the thing abnormal in his condition was a mild, general, rhythmical tremor. At this time, also, after a little coaxing, he walked across the room and drank some milk. The next morning the dog presented no sign of having been misused, but in disposition and demeanor was entirely natural. He so remained until the fifth day after the large dose, when he succumbed to .245 amperes, after these other doses, gradually approaching this strength, or less than one-quarter of the current survived under ether."

We will presently note how the microscope bears out this interesting demonstration, to the effct that lesion, in the ordinary sense, is not necessary to the production of death by electricity; and, further:

Dr. Tatum's paper, February 22, 1890, *New York Medical Journal*, regarding some of his experiments, says: "Whereas a current of one ampere, passed in either direction for one full second, between the head and thigh of a dog weighing not more than sixty pounds, and representing in the neck a current density of as much as a ten thousandth of one ampere to the square millimeter section, invariably causes immediate and permanent arrest of both heart and respiration, yet a current of two and a half amperes has been passed for several seconds from one hind leg to the other of a much smaller dog, and representing a current density ten times as great as that just mentioned, and the dog has immediately afterward risen to his feet and walked away."

"From this and the negative results which the microscope gives in examination of the heart of animals killed by electricity, we may say with the doctor, that somatic death may be caused without serious

lesion of either substance or functions of muscles or nerves, but also that when such lesions do occur they are in no sense the cause, direct or indirect, of death, and can only have resulted from a great excess of current above the fatal strength. A dog was killed by passing a smooth, continuous current of 0.4 ampere between the head and thigh, the positive pole or electrode being applied to the head. The current was then maintained of the same strength and direction for one hour and forty minutes longer, interrupted only by nine momentary breaks, made for the purpose of testing muscular contractility. By the end of this time the whole body was in a fairly firm rigor. This had been first noticed at the end of forty-five minutes, beginning in the neck, extending then to the muscles of the back, and appearing in the thigh, to which one electrode had been applied rather sooner than in the other extremities. Yet after this prolonged application of a fatal dose there was no sign of tissue disintegration or of any liberation of gases in the tissues or in the blood-vessels; nor any lesion whatsoever except a light ecchymosis between the skull and scalp immediately under the electrode. If there is any change at all wrought in the blood, then it is not in the nature of ordinary electrolysis; nor is it of a sufficiently gross character to be readily detected with the microscope; nor does it evidently alter the physiological character of the blood. Until, at least, the existence of some change is proved, it is useless to speculate on its possible nature or consequences." This does not correspond with the result of the examination of blood taken from William Kemmler. (See Plate. The current after the second application must have produced its effect on the blood through its thermeric influence.

The doctor further says: "Respiration may be suspended or inhibited without the immediate arrest of the heart; and, on the other hand, the heart may be instantly and definitively arrested, while the respiratory mechanism yields only gradually. A current of one ampere passed between the head and thigh for one full second, in either direction, or an alternating current of the same virtual strength for one second, has always stopped the heart beat and respiration at once. And, further, the most fatal mode of application has been when one electrode was placed immediately over the heart region, for in three experiments where this plan was tried the heart was stopped by a strength of current and a duration of closure decidedly less than ever sufficed when the current was passed from the head to the thigh.

Dr. A. D. Rockwell has kindly expressed for this paper his opin-

ion on the subject of death from the electric shock: "In regard to the cause of death by the electric shock, I do not feel competent to say more than that it seems to instantly paralyze the heart through its action on the nerve centers. I have witnessed a number of post-mortems after accidental death by electricity, and in every case there was an absence of even a suggestion of tissue lesion, the heart only excepted, and even in this organ the minute effusions following capillary rupture were due to its sudden and powerful contraction, and not the direct action of the current itself."

Now, what does the microscope say?

Interesting in this connection is the report of Professor S. H. Gage, of Cornell University, upon the result of examination of the heart of a calf killed by the Kemmler chair electrodes and Auburn plant:

"In examining the calf's heart muscle which you sent me, I made sections, stained and mounted in balsam. Part of the tissue was isolated with caustic potash, and part simply dissected with needles and mounted in glycerine. In order to have a criterion to guide me, the heart of a calf butchered in the ordinary way for food was obtained, and examinations made while it was fresh, and then after treatment with alcohol, as described, for the heart received from you.

"In the examinations, preparations were taken from the same part of the heart in the two specimens and treated precisely alike.

"RESULTS.—After comparing parallel preparations, made as described above, I am compelled to say that no constant differences could be found. All the examinations were made finally with a Zeiss Apochromatic, $\frac{1}{12}$, ocular X 12.

"There was an indication in the balsam preparations of a difference. In the heart killed by electricity the longitudinal striation of the muscle cells was very clear, the fibrillæ seeming to be separated by a comparatively wide, clear line, and in the fibrillæ the dark band was very marked, giving the appearance of a row of light and dark cubes. From the width of the interfibrillar light line the transverse striation was not so marked as the longitudinal. Later the distinction broke down, as similar if not quite so marked appearances were found in the heart muscle of the butchered calf.

"The nuclei of the muscle cells were scrutinized with the greatest care, but no difference could be discovered. I am sorry not to be able to give a more satisfactory report, but the subtle fluid seemed to kill without leaving gross enough marks for me to detect."

The result of examination by William C. Krauss, M. D., Professor of Pathology, Niagara University, Buffalo, New York, of brain of

same calf killed at Auburn: "The left hemisphere and cerebellum, immersed in alcohol, were presented me for microscopical examination.

"MICROSCOPIC EXAMINATION.—The specimens are in good state of preservation; pia is not adherent; pial vessels are somewhat injected; convolutions present no abnormalities; brain substance is firm and resistant, not brittle, and shows no petechial extravasations on section. There is a slight discoloration of the pia and underlying brain substance over the frontal and occipital lobes. This, no doubt, was produced by the electric current, and the discoloration, in all probability, is the result of thermic action.

"The brain was further hardened in alcohol for three weeks, and small sections taken from the frontal, parietal, temporal, and occipital lobes were imbedded in celloidin preparatory for cutting. No difficulty was experienced in cutting very thin sections. The staining methods used were ammonia, carmine, hæmatoxylon, and Neissl's magenta red.

"The sections took an indistinct diffused stain; the ganglion cells, etc., lacked that sharpness and clearness of outline which characterizes normal brain tissues. Whether this was the result of chemical change or to some fault in hardening, I am unable to say.

"As to the physical condition of the ganglion cells, there appeared to be no material change; nucleus, cell body, and poles were in normal condition. The same was true of the vessels and neuroglia cells. No evidence of hemorrhage into the brain tissue could be discerned. The periganglionic spaces were found free and unobstructed. The result of the microscopic examination is, therefore, negative, as far as the physical condition of the separate brain elements are concerned. Whether the diffused appearance of the sections can be attributed to some chemical change in the protoplasm, I leave unanswered."

A micro-spectroscopic examination of blood by Prof. John A. Miller, Medical Department Niagara University, Buffalo, N. Y., resulted as follows:

Samples of arterial and venous blood of William Kemmler, obtained Saturday, August 9, 1890, from Dr. C. M. Daniels, of Buffalo, were submitted to spectroscopic examination. Both specimens showed the absorption bands of oxhæmoglobin situated between D and E of the spectrum. The position of the lines was identical with those of my own blood. The lines of the arterial blood were identical with those of the venous. The addition of ammonium sulphide caused

the band of hæmoglobin to appear very distinctly. A very interesting feature in regard to these samples is the fact that the reaction of the blood instead of being alkaline is acid.

That these are interesting and valuable results, no one will question.

The conclusion that special lesion of tissue is necessary to the production of death by electricity appears to be answered in the negative so far as the microscope is concerned.

The First Electro-Execution.

The execution of William Kemmler having been set for the week beginning August 4, 1890, on the 5th instant the "committee of reputable citizens" provided by law met at the call of Warden Charles F. Durston at Auburn prison. Your humble servant was constituted an official "reputable citizen" for the first time in his life. Lately, through the press, you may have heard something about their doings at Auburn. Without entering into the preliminary details of the execution, I will proceed at once to give a short account of this first official taking of human life by electricity. Since the former proposed execution, changes had been made in the location of the apparatus to be used for this purpose. When the calf was killed at Auburn, the entire plant of the execution was in one room, with the exception of the dynamo, which was some two or three hundred yards distant, in a separate portion of the prison. Communication with the engineer was by an electric bell. The chair had been removed to another room, so that to witnesses of the execution there was nothing whatever to indicate when the current was working favorably. This I believe undesirable. The lamp-board, the switches, ammeter, and voltmeter were in an adjacent room. The intent of this arrangement was that it might be concealed from the world whom the individual might be who turned on the fatal current. The chair was arranged in the center of one end of the room and securely fastened to the floor and perfectly insulated from it. One wire passed to the spinal electrode, and the other was carried up to the ceiling and brought down to the cerebral electrode. The attachment of the spinal electrode had been modified somewhat by Mr. Durston; a spring having a play of some two or three inches was arranged so that it would hold the electrode in connection with the body of the culprit, so that it was impossible to draw away from it. As the chair was arranged, it was demonstrated that the electrodes could be closely applied to the body; that upon the back,

however, not having been as thoroughly supplied with the saturating fluid as that upon the head.

The details of the culprit's actions in the trying ordeal to which he was subjected I need not repeat, but merely say that William Kemmler went to his death in a manner which won the admiration and respect of all who beheld him, and demonstrated the untruthfulness of many reports which had been circulated about him. However, had he been a powerful, strong individual and objected, there would have been no uncertainty about the carrying out of the penalty. Once strapped in the chair, the most powerful man could not have interfered with the purpose of the law.

In the audience, composed of some twenty-four or twenty-five gentlemen, there were physicians accustomed to sights associated with death. There were others who were incapable of witnessing even the culprit in his chair without fainting; also some interested in giving to the world as sensational an account of the occurrence as was possible.

From reports circulated in the daily press, I note that Mr. Edison objects to the location of electrodes on the head and spine. I am inclined to believe that he has given credence to the many unreliable reports published about the execution. There was no question raised about the ready passage of the current. In fact, as will be noted presently, the electrodes as applied presented the strongest evidence that their location was well advised.

Mr. Edison is reported to base his argument in favor of passing the current through the hands upon the vascularity of these parts. He is reported as saying, "The arms, hands, and fingers are full of blood, and the current should have been forced through them."

It must be noted that we have in the lacunæ, canaliculæ, and haversian canals of the bone a net-work, filled in life with blood, and presenting a vascularity that will compare closely with that of the softer tissue, and thus presenting a very fair conducting medium. The question of paralysis of the psychical centers of the brain, which is obtained by the location of the electrodes, as in the Kemmler chair, is, in my opinion, of vastly more importance than to pass the current through the body with the positive uncertainty of the interference with consciousness, which might ensue if the current was passed through the arms. The difference, if any, in resistance is a factor of inconsiderable consequence in electro-execution, and it did not appear to be of importance in the Kemmler case.

In the case of Kemmler, the head electrode was filled with the

potash solution by an attendant and myself, and, through the spring arrangement which secured it in place and the immovability of the culprit, there was at least one inch in depth of fluid covering the electrode and confined within its rubber cup. In other words, there was no leakage of fluid from this electrode. How interestingly does this answer the question as to the horrible writhings, twistings, and contortions of the body which were reported to the public, and by many reputable medical journals accepted as truthful. "The truth will out." How did I know the electrode did not leak? I removed it myself some twenty minutes after the current was turned off, and the fluid poured down over the head. In this electrode the hair at one edge was merely singed, where an arc had been formed. It was not burned to any extent, not anywhere down to the scalp. There was no question of imperfect contact raised here.

The electrode on the spine did not fit as tightly or hold the fluid so securely, but even then it did its work; but, after the third application of the current, dried up the saturated sponge, which produced the smoke as it burned away (only at one edge, however), thus allowing the brass plate to touch the skin at this point only. A burn, of course, resulted; but Kemmler was a corpse some time before the second application of the current. Will any one question, even if they do not desire to admit, that Kemmler died in the first twenty seconds; that he was not dead at this time, one hundred seconds after first application of current—dead without physical suffering, also? This is the truthful statement of the result of the first electro-execution by one who during its enactment was from two to six feet distant from the culprit.

The true history of the first electro-execution should read thus: Current applied; unconsciousness; death immediately resulted; current kept on about ten seconds—too short a time. Within *20 seconds of first application of current I could detect no pulse* at wrist. Shortly afterwards two or three slight movements of chest took place. After the first application of current there was not a movement, except as above, of a flexor or extensor muscle of either limb or arm; not a twitch of the muscles of face; no reflex action of eyes on removal of head-strap; not, in fact, a move, except what was produced by the make or break of the dynamo current. The man was alive one moment, and dead, so far as the ordinary evidences of death are concerned, the next. Reflex phenomena may be present after death, as is well known, and nothing more than this was present in Kemmler after the first application of the current. As to the import of

chest movement, see Dr. Tatum's results on dogs, already quoted, viz: "In 21 out of 23 dogs killed by the application of electricity, effective respiration survived the final heart arrest. Fair inspirations were recorded in several cases as long as four or five minutes after the dose, which lasted only one second, but after which the heart had not executed a single beat that could be detected." My own demonstrations point to the same conclusions as in the second dog operated on—the heart ceased beating instantly, but attempts at respiration were made afterwards.

From these reasons I cannot agree with Dr. Shrady, one of the few witnesses who reported adversely to the method, as to possibility of resuscitation of Kemmler at this time. See also testimony, No. 3777, Kemmler inquiry, where a Mr. Smith respired some time after contact with brushes of a dynamo, which destroyed life. There is also plenty of evidence to show that respiration following heart arrest has been kept up in individuals subjected to powerful electric stroke for some time where resuscitation was impossible and the heart had ceased to beat. However, the current was re-applied within 70 seconds. As might be expected, when its influence reached the muscular coats of stomach, a contraction took place, causing a small amount of mucous to ooze from the mouth—not fly all over the room, as one report states. This is a good indication of death, also. One hundred seconds had now elapsed, *at farthest*, since the application of the first current. But Kemmler was dead at the first application of current, and with not one iota of feeling, as I stated, at the time.

It can be truthfully stated that the first electro-execution, inspired in the interests of humanity, and with the methods employed, has demonstrated the truthfulness of all that has been claimed by its advocates. If criminals *must be executed* there is no method so certain and ready of applicability if the apparatus is properly provided.

I will here leave to those who have followed me through this discussion, so incompletely presented, the privilege of drawing their own conclusions, having no question in my mind as to the result.*

* I am indebted to Mr. Henry L. Tolman for the photo-micrographs of blood which accompan this article.—G. E. F.

PLATE I. No. 1.

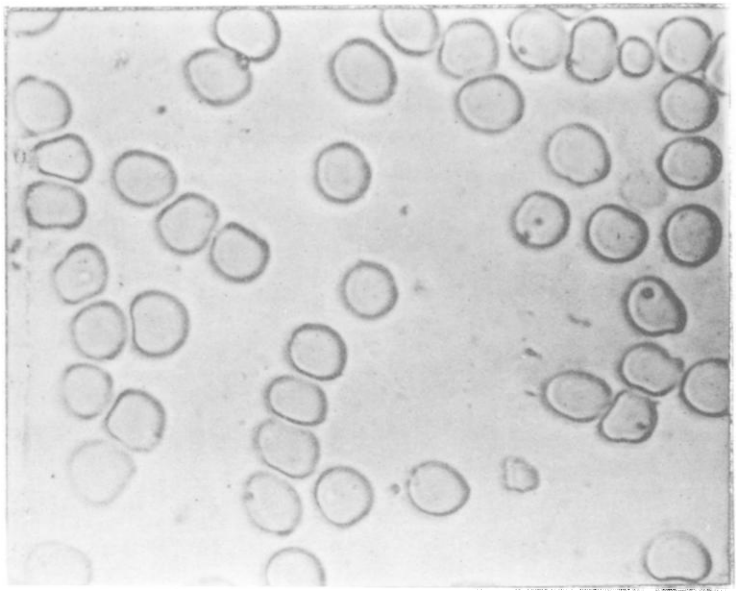

PLATE I. No. 2.

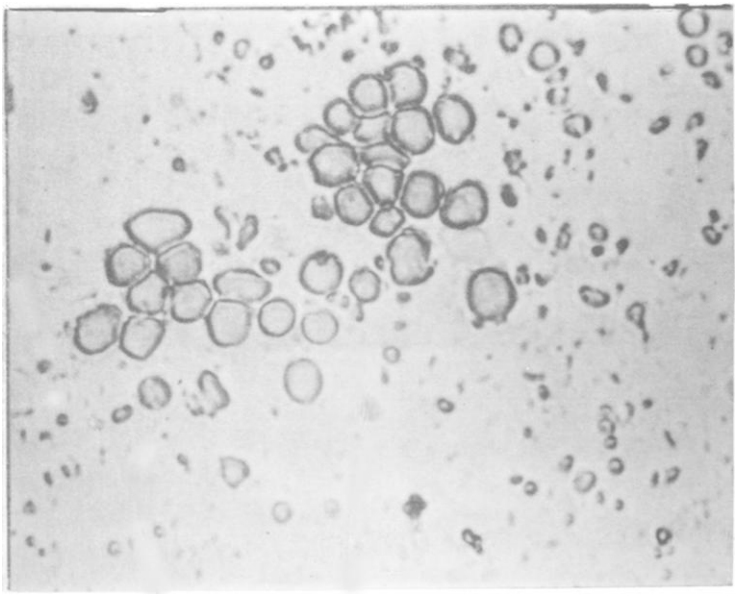

PHOTO-COLLOTYPE, HOFE M'F'G CO., PHILADELPHIA.

Description of Plates.

PLATE I, NO. 1.—Photomicrograph of blood taken from outer aspect left thigh half an hour after the execution. This portion of the body did not come under the direct influence of the current. The corpuscles present a normal appearance as to size and uniformity of outline.

PLATES I AND II, NOS. 2, 3, AND 4.—Photomicrographs of blood taken from left temple seven minutes after the execution and almost directly under the influence of the current. Corpuscles markedly reduced in size, in many cases to merely granular particles of protoplasm and with irregularity of outline. Nos. 2, 3, and 4 taken from different sections of same slide.

I am indebted to Mr. Tolman, of Chicago, for the photographs of the Kemmler blood.

G. E. F.

PLATE II. No. 3.

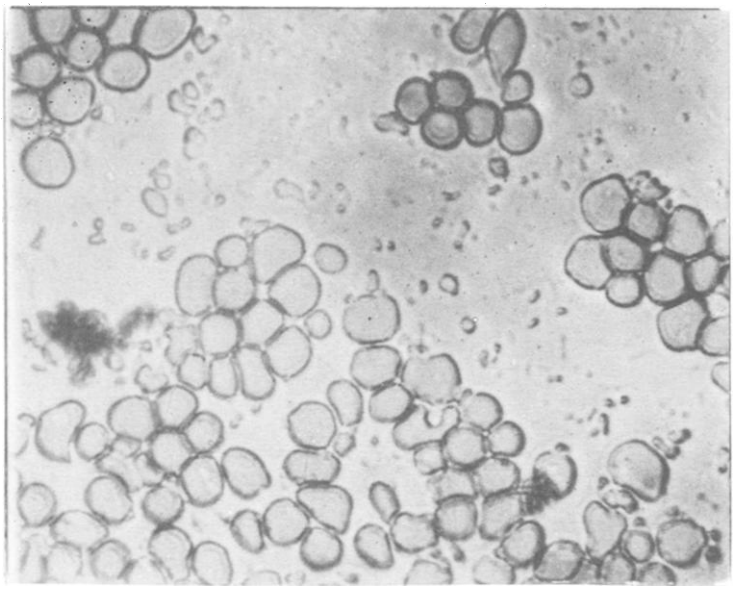

PLATE II. No. 4.

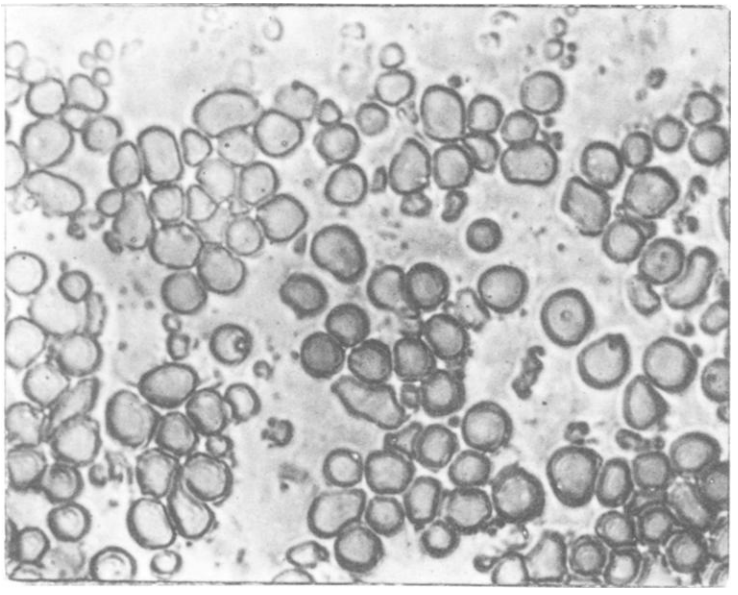

PHOTO-COLLOTYPE, HOPE M'F'G CO., PHILADELPHIA